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Analysis of an explosion accident at Dangyang Power Plant in Hubei, China: Causes and lessons learned

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ABSTRACT

On August 11, 2016, an explosion of a high-pressure steam pipeline occurred at a power plant in Dangyang City, Hubei Province, China. The accident killed 22 people and 4 people were injured. The causal factors of the accident were analyzed to prevent such catastrophe in the future. The entire accident process was divided into three sequential events for respective analysis based on timeline. Furthermore, a new model demonstrating the relationships among different causal factors was proposed and applied for this accident analysis. With respect to the power plant, the deficiencies from five causal categories were identified, which clearly demonstrated the accident mechanism from immediate causes to root causes. The results of the analysis indicated that unsafe acts performed by staff from different levels in power plant led to unsafe conditions, which were due to three factors, i.e., staff's inadequate safety knowledge, weak safety awareness and bad safety habits. The elements in safety management system (e.g., "procurement," "determination of applicable legal requirements and other requirements") were not implemented and maintained. Moreover, the staff did not reach a consensus on specific safety beliefs (e.g., "safety is the first priority," "the importance of top management commitment"), which indicated poor safety culture in the organization. Finally, in order to prevent the recurrences of similar accidents, the major lessons learned from this explosion were proposed and the application of the analysis results for related safety training was discussed.

1. Accident background

On August 11, 2016, around 3:20 p.m. (local time), a high-pressure steam pipeline exploded at Madian Gangue Power Generation Co., Ltd., located in Dangyang City, Hubei, China (hereafter, Dangyang Power Plant). The explosion caused hot steam leakage, which killed 22 people and injured 4 (The Beijing News, 2016). The exploded steam pipeline was a part of a 50 MW heat-electricity cogeneration reconstruction project in Dangyang Power Plant (Office of Work Safety Committee, 2016; People's Daily Online, 2016). The reconstruction project was approved by the Hubei Provincial Development and Reform Commission in 2012 and the construction started in January 2015. By May 2016, the installation of the main equipment was completed and it was under trial operation from the middle of June 2016 till the explosion accident occurred (Xinhua Net, 2016). The process of this project was as follows: coal and gangue were mixed and burnt in the boiler furnace to produce heat; this heat was then used to boil water in the boiler to produce high-pressure and high-temperature steam; further the steam was piped to a steam turbine, which propelled its rotation to produce electricity (Xinhua Net, 2016).

The cracked steam pipeline was located in a room on the third floor of a plant building where massive steam pipelines were arranged; and the main control room was next door, separated by a piece of double-pane glass. The investigation indicated that the cracked location was the weld in the flowmeter of the main steam pipeline which was located in the steam outlet of the No. 2 boiler (Hubei Provincial Safety Production Supervision Authority, 2017; Xinhua Net, 2016). When the explosion occurred, there were operators and managers in the main control room who were killed and injured by the explosion's shock wave and leaked hot steam with the temperature of 530 °C; moreover, the explosion caused damage to the facilities (Hubei Provincial Safety Production Supervision Authority, 2017; Office of Work Safety Committee, 2016; Xinhua Net, 2016). Figs. 1 and 2 show the photographs of the accident scene.

The official accident investigation report has been released (Hubei Provincial Safety Production Supervision Authority, 2017); in addition,

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Fig. 1. Scene of steam pipeline explosion (Xinhua Net, 2016).

Fig. 2. Scene of the main control room after explosion (Xinhua Net, 2016).

available information about the process of the catastrophe was also provided on the Internet (Netease, 2016; Xinhua Net, 2016). Based on the obtained information, it is certain that the accident could be prevented if the plant attached more attention to safety during its operation. In order to understand how and why the accident occurred, a new model illustrating the accident mechanism from immediate causes to root causes was adopted to analyze the accident. Whereafter, based on the analysis results, recommendations were proposed from individual level to organizational level for preventing such accidents in the future. Besides, as a case study, the application of the analysis results for the relevant safety training was discussed, which provided a new approach for learning from accidents.

2. Methodology

2.1. Sequence of accident

The sequential occurrences of multiple adverse events resulted in the accident. A day before the explosion (August 10), the steam pipeline began to leak and one of the staff was injured on foot; however, there was no mitigation action taken to repair and the plant was still in operation. On the morning of August 11, the steam pipeline leaked again. There was still no action to prevent the situation from getting worse and the trial operation kept running till the steam pipeline exploded in the afternoon (Hubei Provincial Safety Production Supervision Authority, 2017; Netease, 2016). Thus, the entire process of this accident can be divided into following three sequential events based on its timeline: (1) on August 10, the weld in the flowmeter of the main steam pipeline cracked; (2) countermeasures were not adopted timely, which expanded the cracked weld and led to the explosion; and (3) the explosion's shock wave and hot steam reached the adjacent main control room, causing casualties and property losses. The sequence of this accident is illustrated by Event Sequence Diagram (ESD) as shown in Fig. 3.

2.2. Approach to accident analysis

Accident models demonstrate the relations between causes and effects (Qureshi, 2007); therefore, a new accident model was proposed in this study to analyze the mechanism of the catastrophe. It is now generally accepted that accidents are caused by interactions among causal factors residing at all levels of the sociotechnical systems, from government to individuals in the involved organization (Leveson, 2004; Rasmussen, 1997). For the sake of simplicity, causal factors can be classified based on the manageable boundary of the organization as "external causes" and "internal causes" (Fu et al., 2017; Omole and Walker, 2015; Rasmussen, 1997). The "internal causes" are much more changeable and controllable for the managers of the organization to achieve improvement in safety performance; therefore, they are mainly analyzed in this study.

According to Heinrich's Domino theory, unsafe acts and unsafe conditions are the immediate causes of an accident (Heinrich et al., 1980); moreover, there also exist mutual impacts among them (Chi et al., 2013). The immediate causes have been proved to be determined by various factors, such as individuals' safety knowledge (Fu et al., 2017;Neal et al., 2000), safety awareness (Fu et al., 2005, 2013; Fu, 2013), safety habits (Fu et al., 2013), as well as their mental and physiological status (Fu et al., 2017;Wiegmann and Shappell, 2003). There was inadequate information to verify or deduce the individual's mental and physiological status during accident; therefore, this study mainly focused on the influences brought by individual's inadequate safety knowledge, safety awareness and safety habits leading to unsafe acts. It is recognized that the errors from individual level are led by root causes, i.e., the weaknesses in organizational safety management and safety culture (Reason, 1997). The safety management in an organization is carried out via safety management system (Kennedy and Kirwan, 1998); therefore, the defects in safety management system in turn can be used as indicators to illustrate and reflect the flaws in safety management. Safety culture, which reflects the beliefs, values, and attitudes shared by the employees in relation to safety (Cox and Cox, 1991; Fu, 2013), guides the development and implementation of safety management system; thus, the poor safety culture in an organization leads to the deficient safety management system (Fu et al., 2009, 2017).

The above description can be illustrated as a model presented in Fig. 4. The red[3] dotted line is the manageable boundary of an organization which divides all the causes in sociotechnical systems into "external causes" and "internal causes." The "internal causes" are classified into five causal categories from individual deficiencies to organizational flaws, which are indicated by the blue boxes. The blue arrows indicate the sequence of internal causes leading to an accident, from deficiencies in organization's safety culture to the weaknesses in safety management system, to the flaws in individual's safety knowledge, safety awareness, as well as safety habits, to unsafe acts and unsafe conditions (there is a correlation between unsafe acts and unsafe conditions), eventually to an accident. The red arrows indicate the accident analysis steps, which begin from the bad outcomes (i.e., accident) to the immediate causes (i.e., the unsafe acts and unsafe conditions), to flaws in employee's safety knowledge, safety awareness and safety habits, to the deficiencies in organization's safety management system, and finally to weaknesses in safety culture.

The casualties and property losses are the culmination of the

[3] For interpretation of color in 'Fig. 4', the reader is referred to the web version of this article.